



# Producibility Aspects of Composite Material Qualification and Certification



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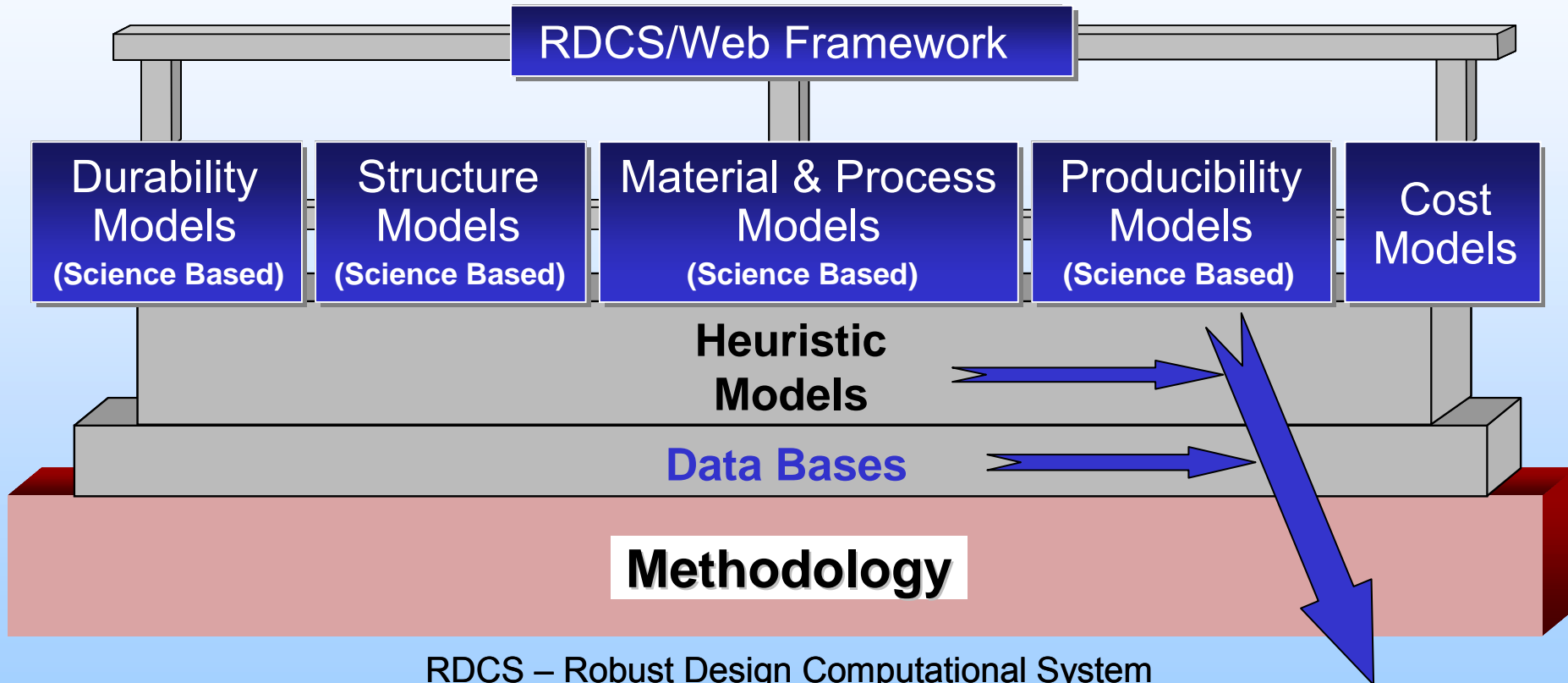
**Jointly accomplished by BOEING Led Team and the U.S. Government  
under the guidance of NAST (TIA N00421-01-3-0098)**

*This program was developed under the guidance of Dr. Steve Wax and  
Dr. Leo Christodoulou of DARPA. It is under the technical direction of  
Dr. Ray Meilunas of NAVAIR.*



# Overall Program Concept

The Objective of the AIM-C Program is to Provide Concepts, an Approach, and Tools That Can Accelerate the Insertion of Composite Materials Into DoD Products



RDCS – Robust Design Computational System

**Module:** linked set of related models/databases; 8 in AIM-C Phase I Program - Resin, Fiber, Prepreg, Processing, Lamina, Structures, Durability, and **Producibility**



# Producibility Module Definitions

## Definition:

***A Controller Module to Compare Requirements to Manufacturing Capabilities For Quality Components***

## Corollaries:

- ***Can I Make It?***
  - ***With What Degree of Success?***
  - ***How Can I Make It?***
  - ***By Which Manufacturing Sequence Should It Be Made?***
- **The Initial Envisioned Module Provides Heuristics Which Give Guidance Through Part Thermal Processing (Cure/Post Cure)**
  - **Higher Level Module That Manages And Guides The Other Modules To Exercise Only The Tools That Are Necessary To Address The Designers Requirements**
  - **Phase 1 Program Only Looking At Autoclave Processing**



# Producibility Module Definitions

## Additional Definitions:

### ➤ Manufacturing Capabilities

- Ability to Fabricate the Unassembled Components with Identified Materials and Manufacturing Methods

### ➤ Manufacturing/Processing Steps/Areas

- Ply Cutting
- Layup
- Debulking
- Bagging
- Equipment
- Tooling
- Repairability

### ➤ Quality Requirements/Parameters

- Meets Functional Requirements (Strength, Stiffness, Dimensions, Etc.)
- Requirements/Parameters are Identifiable, Measurable, and Boundable

### ➤ Component Quality Requirements/Parameters

- Dimensions
- Voids
- Porosity
- Inclusions
- Surface Waviness
- Fiber Volume/Resin Content
- In-Plane & Out of Plane Fiber Distortion
- Surface Finish

### ➤ In-Process Quality Requirements/Parameters

- Ply Angle
- Ply Lap/Gap
- Out Time
- Freezer Time
- Equipment Certifications
- Heat-up Rates
- Cure Time, Temp, Pressure
- Abort Conditions
- Debulk Time, Temp, Pressure



# Module Functional Flow Chart

## Design User Requirements

- Kind of Structure (Skins, Substructure, Doors, Etc.)
- Class of Structure (Primary, Secondary, etc.)
- Type of Structure (Monolithic, Cocure, Etc.)
- Configuration/Features
- Tolerances
- Fiber/Fiber Form
- Fiber Volume/Resin Content
- Quality (Voids, etc.)
- Additional Mat'l's
- Secondary Operations
- Repairability
- Manufacturing Methods

## Other User Requirements

## Certification User Requirements

- Changed Mat'l, Process, Equipment, Tooling

CAD Master  
Data Tie

## Modules/RDCS

- Resin
- Fiber
- Prepreg
- Processing
- Lamina
- Structure
- Durability

Variability/  
Error Analysis  
Results

Key Mat'l  
& Process  
Controls

## Knowledge Bases

- Lessons Learned
- Structure Kind, Type..
- Configuration
- Parts
- Secondary Operations
- Repairability
- Sourcing Capabilities/Capacities
- Equipment
- Tooling
- Quality
- Test Methods

**Producibility  
Module**

Methodology  
(Divergence/Risk)

CACC

CAICAT, ATMCS,  
FiberSim, Panform

Outputs

- Divergence/Risk for Requirements Relative to Capabilities
- Risk Reduction Recommendations
- Costs/Times
- Design/Manufacturing Recommendations
- Mat'l & Process Spec Recommendations
- Quality Plan/Recommendations
- Indirect Materials
- Tooling Definitions/Concepts



# Producibility Module Software

*Most aspects of producibility are very subjective and/or based on previous experience with very little existing software. Therefore, it is proposed to use existing software capable of logical programming along with data bases that will contain pertinent information to be interrogated through SQL.*

- **Heuristic and/or Rule Based Software**  
(**Java**, Visual Basic, C++....)
- **Knowledge/Data Bases**  
(Access, **Oracle**, M-Vision,...)
- **Science Based Objective Models**  
(Fortran, C++, etc.)
  - **CACC** (**Thickness**, Voids/Porosity, Resin Flow Bagging, Debulking, **Tooling**, etc.)



# Knowledge/Data Bases

## Manufacturing/Processing Steps

- Cutting
- Layup
- Debulking
- Cure
- NDE/Quality
- Testing

## Equipment

- Cutting
- Collation
- Ovens
- Autoclaves
- NDE
- Testing

## Lessons Learned

- Configuration/Type/Class (Parts)
- Methodology
- Material(s) and Material Combinations
- Manufacturing/Processing Steps
- Tooling
- Equipment
- Quality (In-process and Final Part)
- Testing/Evaluations
- Secondary Operations
- Repair
- RDT&E Costs/Times?

## Tooling

- Primary Tooling
- Secondary Tooling

## Secondary Operations

- Bonding
- Painting
- Coating

## Repair

- In-process
- Final Part (After Cure)
- Material Compatibility

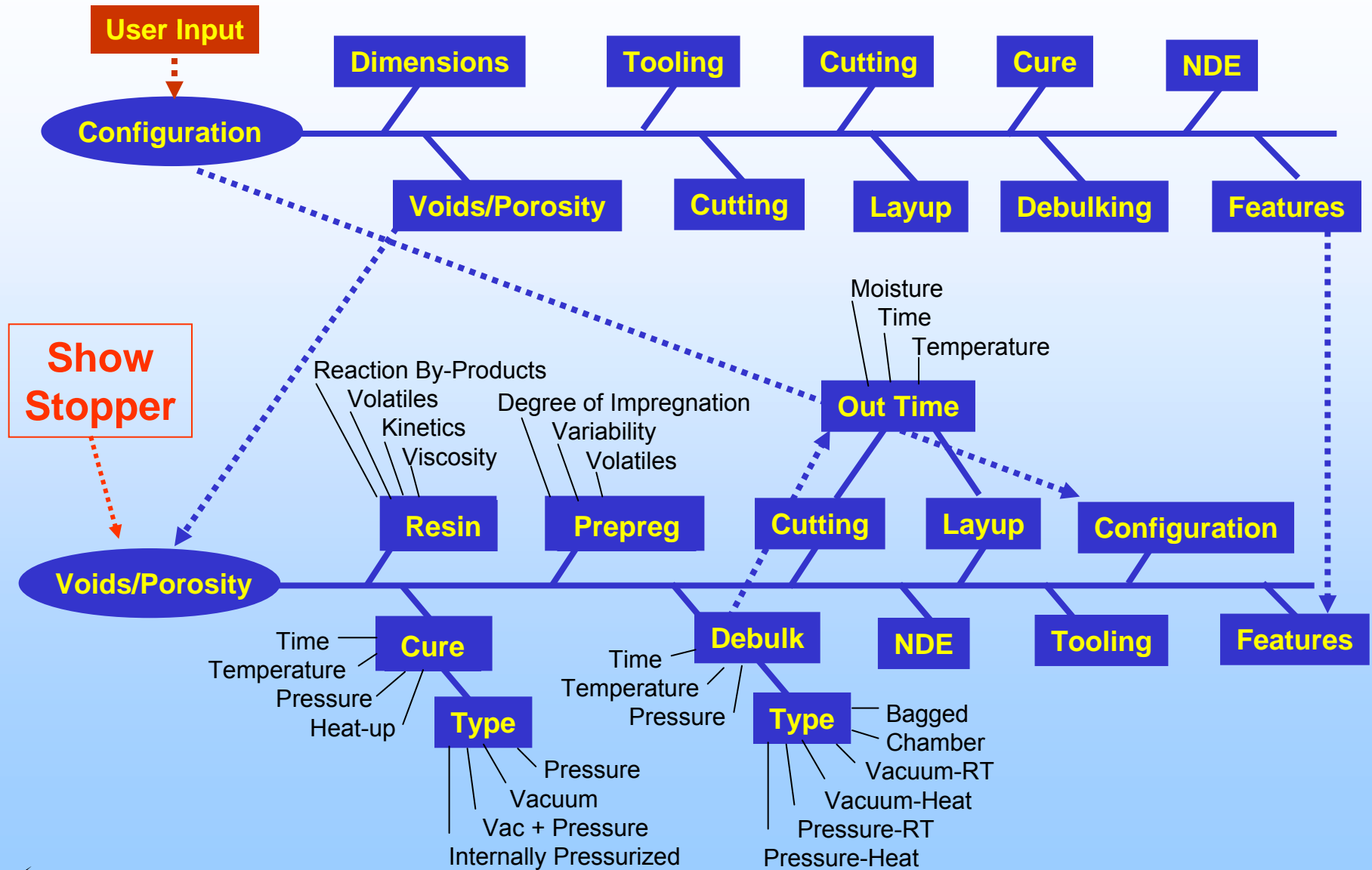
## Other

- Health & Safety
- ITAR
- Proprietary Info





# Cause and Effect Diagrams

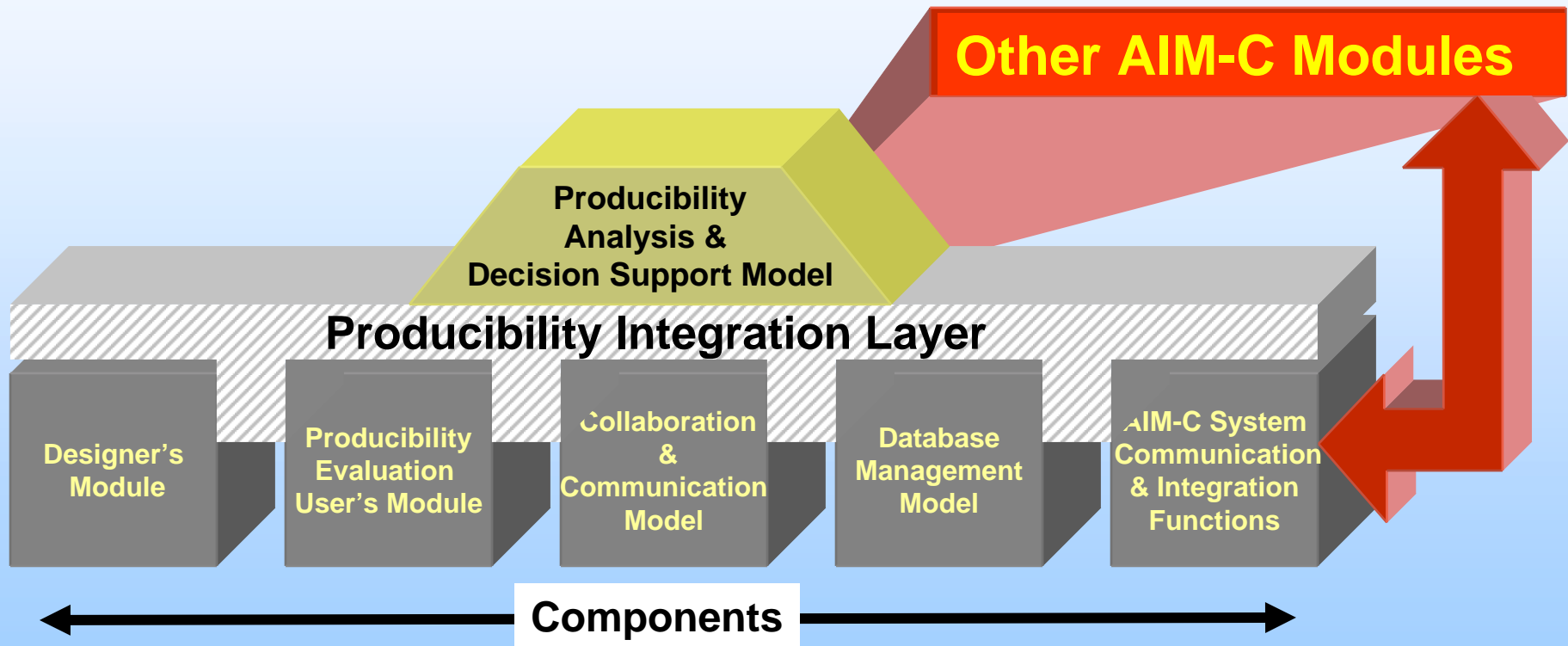






# AIM-C Producibility Module

*Producibility Module Has Integrated Components That In Turn.....*

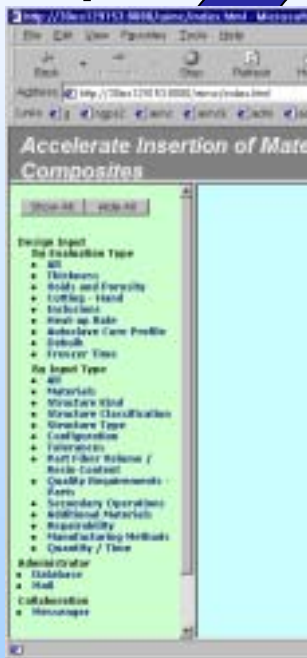


*.....Are Integrated With Other AIM-C Modules*



# Producibility Module Demo Overview

Design User  
Inputs



- Primary Matl's
- Size/Thickness
- Features
- Tolerances
- Quality Requirements

Producibility  
Item(s)  
Evaluation



- Thickness
- Voids/Porosity
- Cutting
- Indirect Matl's

Knowledge/Data  
Bases

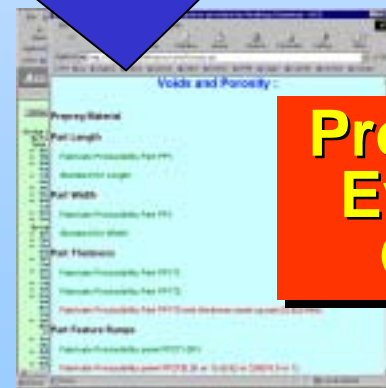
Referenced/  
Required  
Information

Lessons  
Learned

Indirect  
Materials

Testing/  
Specs

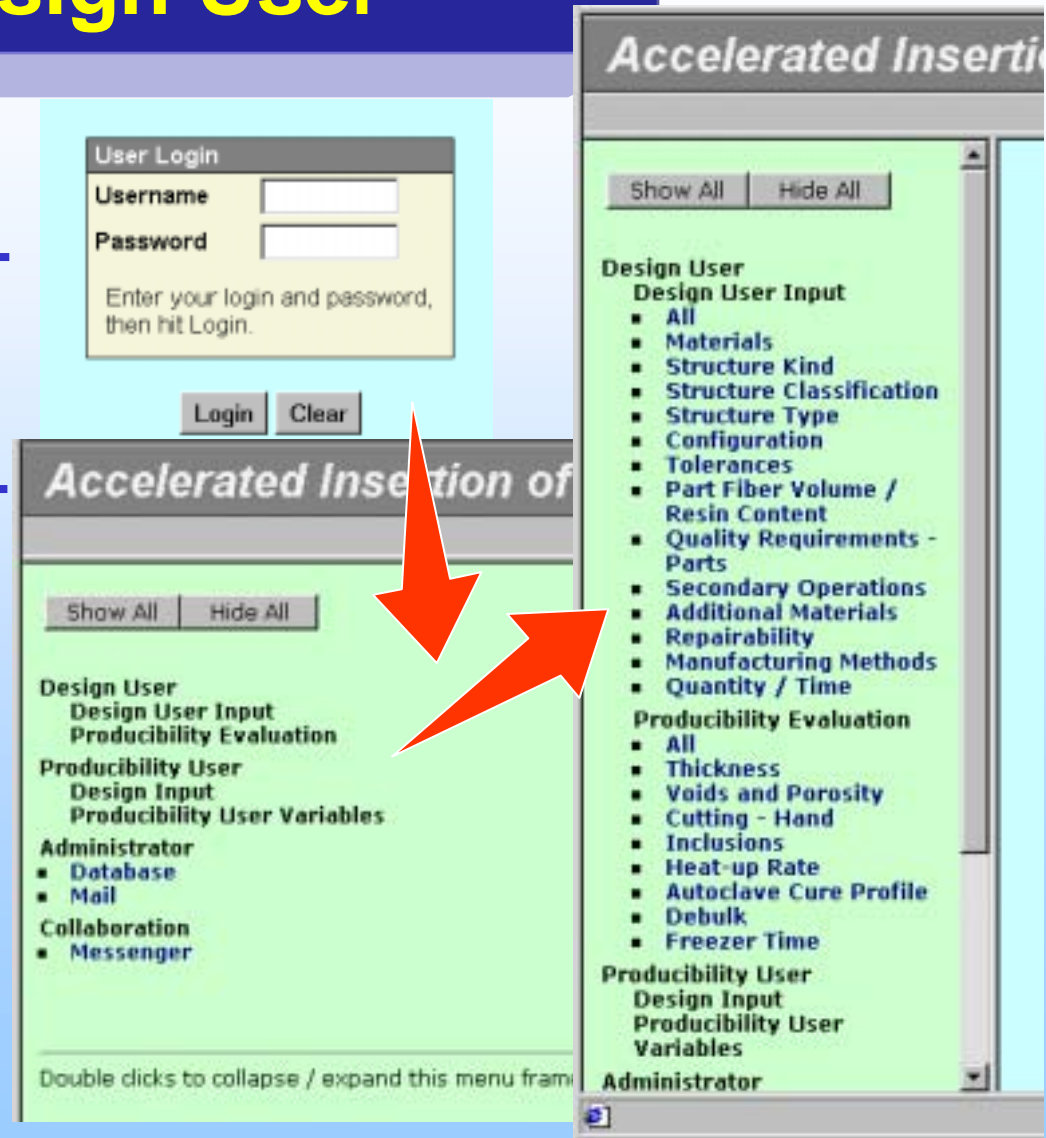
Producibility  
Evaluation  
Outputs





# Starting Module Design User

- **Control of Users**
- **Multiple User Types**
- **Administration Control for Data Bases**
- **Design User Variables for Producibility**
- **Producibility Evaluations From a Design User Standpoint**
- **Producibility Evaluations From a Producibility User Standpoint**





# Design User Inputs

## Design User Definable Variables

- Design User Sets Problem/Requirements For Producibility Evaluations
- Ties to Other Design User Items
- Allows Individual Producibility Item Evaluations or All Items

**Materials**

Show All Hide All

**Design User**

- Design User Input
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber Volume / Resin Content
- Quality Requirements - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time
- Producibility Evaluation
- Producibility User Design Input

**Materials Table:**

Resin 1:	Type:	977-3				
Fiber 1:	Type:	3K	Form:	SHS	Kind:	AS4
PrePreg 1:	Type:	graphite epoxy	Resin Content		Areal Weight	
Resin 2:	Type:	977-3				
PrePreg 2:	Type:		Kind:	AS4	Areal Weight	
Resin 3:	Type:					
Fiber 3:	Type:		Kind:	AS4	Areal Weight	
PrePreg 3:	Type:					
Resin 4:	Type:	977-3				
Fiber 4:	Type:	3K	Kind:	AS4	Areal Weight	
PrePreg 4:	Type:	graphite epoxy				

**Structure Kind**

Skin(s)

**Structure Kind**

Fairings

*Producibility Evaluations/Outputs  
According to User Inputs/Requirements*



# Producibility – Quality Thickness

Show All Hide All

**Design User**

**Design User Input**

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber Volume / Resin Content
- Quality Requirements - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

**Producibility Evaluation**

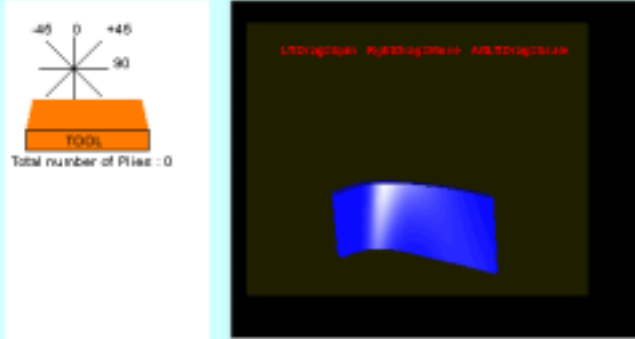
- All
- Thickness**
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

**Producibility User**

**Design Input**

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type

## Thickness for Producibility Evaluation



Total number of Pieces : 0

Please specify part parameters and click Calculate :

**Calculate** **Open** **Save**

### Tolerance Requirements

Prepreg Thickness:					
Part Thickness:	Min:		Max:		
Tolerance Values	Nom:		Min:		Max:

*Ties to Resin,  
Fiber, and  
Prepreg  
Modules*





# Producibility – Quality: Thickness

Thickness for Producibility Evaluation				
	Avg	Min	Max	
Number of Piles	N/A	25	76	
Per Ply Thickness	0	0	0	
Min Part Thickness	0	0	0	
Max Part Thickness	0	0	0	

Problem: min part thickness is 0

Problem: max part thickness is 0

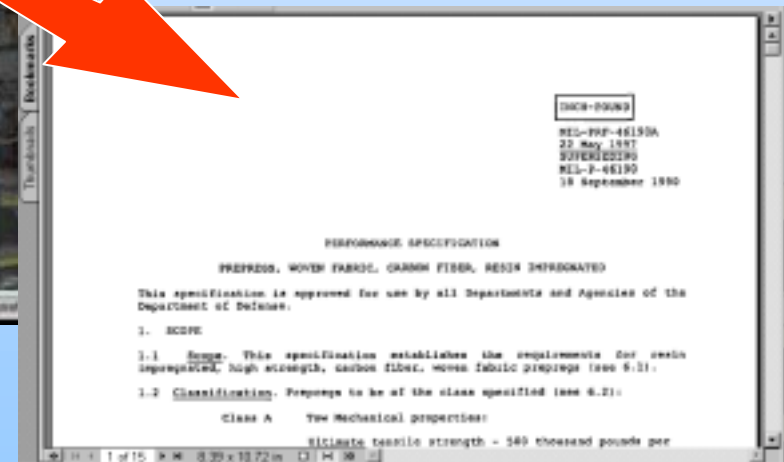
[View Test Method](#)

Testing

*Multiple Output  
Options and  
Information*

Specifications

*Identification of  
Potential  
Problems*





# Producibility – Quality: Voids

Show All Hide All

Design User

- Design User Input
  - All
  - Materials
  - Structure Kind
  - Structure Classification
  - Structure Type
  - Configuration
  - Tolerances
  - Part Fiber Volume / Resin Content
  - Quality Requirements
- Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

Producibility Evaluation

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Producibility User

- Design Input
- All

## Voids and Porosity Relative to Size, Thickness, and Feature Ramps

Please specify part parameters and click Calculate :

Calculate Open Save

Prepreg:	Resin Type	977-3	
	Fiber Type	3K	
	Prepreg Type	graphite epoxy	
Length:	Minimum (in):		Maximum (in):
Width:	Minimum (in):		Maximum (in):
Thickness:	Minimum (in):		Maximum (in):
Ramps:	Min Thickness (in):		Max Thickness (in):
	Ramp Ratio:		Step Thickness (in):
Max. Void %			





# Producibility – Quality: Voids

## Voids and Porosity :

### Prepreg Material

### Part Length

Fabricate Producibility Part PP1 (view).

Standard for Length

### Part Width

Fabricate Producibility Part PP1 (view).

Standard for Width

### Part Thickness

Fabricate Producibility Part PP1T1 (view) and Thin test panel (0.0) inches thick.

Fabricate Producibility Part PP1T2 (view).

Fabricate Producibility Part PP1T3 (view) and thickness scale-up part (0.0) thick.

### Part Feature Ramps

Fabricate Producibility panel PP2T1-2R1 (view).

Fabricate Producibility panel PP2T(0.0 or 1)-(0.0 or 2)R(0.0 or 1) (view).

### Part Quantity - Voids

#### NDE Standards (Effect of Defect)

Fabricate NDE standard part PP\_NDE2 (view) with (0.0 %) voids.

Fabricate NDE standard part PP\_NDE2 (view) with 2X(0.0 %) voids.

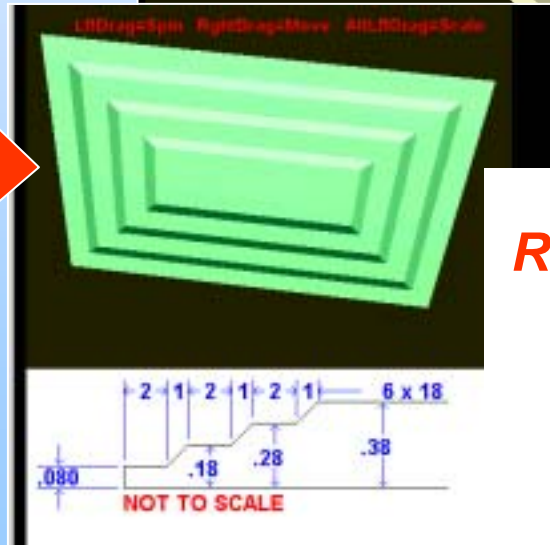
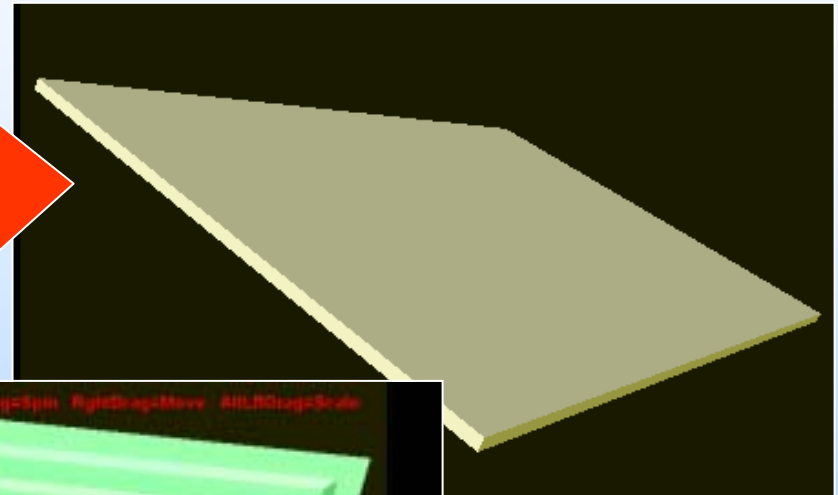
Fabricate NDE standard part PP\_NDE2 (view) with 3X(0.0 %) voids.

#### Mechanical Property Panels (Effect of Defect)

Fabricate Compression test Panel(s) CTP1 (view) with (0.0 %) voids.

Fabricate Compression test Panel(s) CTP1 (view) with 2X(0.0 %) voids.

Fabricate Compression test Panel(s) CTP1 (view) with 3X(0.0 %) voids.



**Output  
Recommendations  
Based on User  
Inputs, Std  
Produce Tests,  
and Lessons  
Learned**



# Producibility – Method: Cutting

**Producibility User Design Input**

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber
- Volume / Resin Content
- Quality Requirements - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

**Producibility User Variables**

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Administrator Collaboration

### Cutting - Hand

Please specify Product Name and click Calculate :

**Calculate** **Open** **Save**

Resin:	Type:	977-3				
Fiber:	Type:	3K	Form:	5HS	Kind: AS4	
Backing Paper:	Product Name:	Product A				
Separator Material:	Product Name:	Product A				
Spool Requirements:	Facility:	Boeing	Weight(lbs):	10	Diameter(Inches): 5	Width(Inches): 100
Resin Environment Requirements:	Storage greater than 5'					
Part Quality:	Inclusions:	Cutting				
In process Quality:	Angle Accuracy:	Facility:	Boeing	Cutting Angle Accuracy:	overall average	

**Methods Take Into Account Facilities/Capabilities, Direct Materials, Indirect Materials, Part Quality, In-Process Quality, and Interactions With Other Items**



# Producibility – Method: Cutting

## Results for Cutting - Hand

### Prepreg Material - Indirect Materials

#### Backing Paper

Product A associated with Prepreg

Evaluate prepreg backing paper per??? Specification for NDE detectability and contamination.

Product A associated with NDE Compatibility

Evaluate prepreg backing paper per??? Specification for contamination.

#### Separator Material

Evaluate prepreg separator per??? Specification for prepreg usage.

Product A associated with ResinID 1

Product A associated with NDE Compatibility

Evaluate prepreg separator per??? Specification for prepreg usage, NDE detectability, and contamination.

### Prepreg Material - Spool Requirements

#### Cutting Capability

There is a conflict between cutting capabilities and prepreg spool ???, Needs investigation.

#### Resin Environment Requirements

### Prepreg Material - Spool Requirements

#### Cutting Capability

There is a conflict between cutting capabilities and prepreg spool ???, Needs investigation.

#### Resin Environment Requirements

TBD.

### Part Quality - Inclusion

#### Indirect Materials - Cutting

Product A associated with Cutting

Evaluate cutting separator per??? Specification for prepreg usage.

Product A associated with NDE Compatibility

Evaluate cutting separator per??? Specification for prepreg usage, NDE detectability, and contamination.

### In-process Quality - Angle Accuracy

Angle accuracy capability (total layup angle accuracy/repeatability) can not meet quality requirements of [angle accuracy] because cutting accuracy/repeatability is ?? And layup accuracy/repeatability is ??.

### Secondary Operations

ttest per ??? Specification

### Part Dimensions



# Producibility User Producibility – Quality: Thickness

**Producibility User**  
Design Input

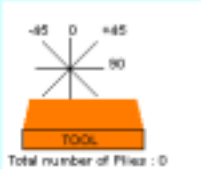
- All
- Materials
- Structure Kind
- Structure
- Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber
- Volume / Resin Content
- Quality Requirements - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

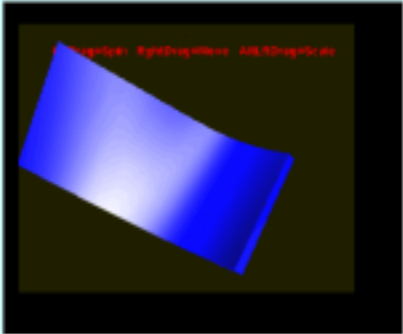
**Producibility User Variables**

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

**Administrator Collaboration**

**Thickness for Producibility User Variables**





Please specify part parameters and click Calculate :

**Calculate** **Open** **Save**

**Tolerance Requirements**

Tolerance Values	Nom:	Min:	Max:

Ply Set 1:	# of Plies:		Orientation:	0	0
PrePreg 1:	Type:	graphite epoxy			
Fiber 1:	Type:	3K	Form:	SHS	Kind: AS4
Resin 1:	Type:	977-3			

Applet started Local intranet

**The Module Is  
Flexible So Different  
Users Can Use It  
For Their Needs  
Later In a  
Development Cycle**





# Producibility User

## Producibility – Quality: Thickness

Producibility User Design Input

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber
- Volume / Resin Content
- Quality Requirements - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

Producibility User Variables

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Administrator Collaboration

Total number of Plies : 12

Please specify part parameters and click Calculate :

**Calculate** **Open** **Save**

**Tolerance Requirements**

Tolerance Values	None	Min	Max
Ply Set 1:	# of Plies: 3	Orientation: -45	-45
PrePreg 1:	Type: graphite epoxy		
Fiber 1:	Type: 3K	Form: SHS	Kind: AS4
Resin 1:	Type: 977.3		
Ply Set 2:	# of Plies: 4	Orientation: 90	90

**Thickness for Producibility User Variables**

Thickness	Min	Max	Avg	Range
Part	0.167646	0.16918	0.163366	0.011534
per ply (set 1)	0.013137	0.014098	0.013613	0.000961
per ply (set 2)	0.013137	0.014098	0.013613	0.000961
per ply (set 3)	0.013137	0.014098	0.013613	0.000961
per ply (set 4)	0.013137	0.014098	0.013613	0.000961

**Good: thickness variations within tolerance**

**Visual Method**

**Output According To Needs**



# Administrator User Data Base Management

**Please select a database**

You are editing AIMC Database. You can select and view any table, or run any SQL query.

Driver:

URL:  (must be in a form the driver understands)

Login:

Password:

**Tables found**

You are connected to relational database, driver is sun.jdbc.odbc.JdbcOdbcDriver

Choose table

To execute a SQL query, enter it below, or choose from the list of previously run queries on the right.

**Maintainability and Information Updating Is Critical....**



# Collaboration User Messenger

**Inclusions**

- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

**Producibility User Design Input**

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber Volume / Resin Content
- Quality Requirements - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

**Producibility User Variables**

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

**Administrator**

- Database
- Mail

**Collaboration**

- Messenger**

**Al Burrows**  
AIMC Guru

**Areas of Ownership:**  
Cutting - Hand

**Address Book:**

- Email: [burrows@mail.northgrum.com](mailto:burrows@mail.northgrum.com)
- Phone: (310)123-4567
- Address: 888 West 190th St, Suite 888
- Department: YB99/UNK

[burrows@mail.northgrum.com](mailto:burrows@mail.northgrum.com)

Icons: Phone, Mail, Messenger





# Summary

- ***Basic Effort Accomplishments:***
  - Design User Interface for Producibility
  - Producibility Quality Areas of Thickness and Voids
  - Producibility Operation/Processing Area of Cutting and Indirect Materials
  - Recommendations Based on Inputs and Lessons Learned
  - Integration of Producibility Module Multiple Component Pieces
  - Integration of Producibility Module with other Modules



## Future Plans

- Populate Module For Core Flat Panel Fabrication Producibility Analysis
- Populate Module For Panel With Ramp Feature Fabrication Producibility Analysis
- Populate Module For Flat Panel With Co-cured Hat Stiffener Fabrication Producibility Analysis
- Populate Module To Perform Producibility Analysis With Combination Of Co-Cured Hat Stiffened Panels And Ramps To Support The Compelling Demonstration



# A Feature Based Producibility Assessment Through Parameterized Process Modeling

- Motivation

- Augment current heuristic approach for cure cycle design with a physics based prediction methodology
- Make a high-end **analysis** tool (AIM-C Processing Module) available for **design** through RDCS
- Demonstrate integration between the web based front-end of Producibility and RDCS

- Integration approach

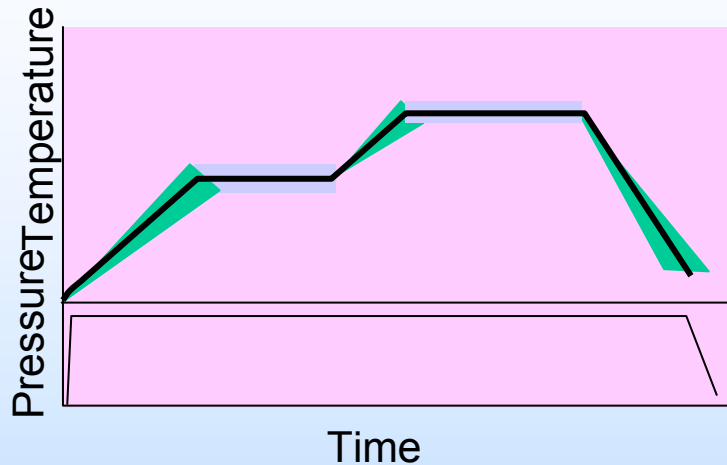
- Parameterize AIM-C Processing Module input/output
- AIM-C Processing Module embedded in a Math model
- Web based GUI for a design process (genetic optimization)
- Producibility module creates RDCS batch file
- Pilot version of invoking RDCS on the designer's desktop
- Design exploration to find cure cycle that meets heat-up requirements

- Accomplishments

- Designed feasible curing cycle that met heat-up requirements
- Identified fabrication processes that are likely to result in defective parts

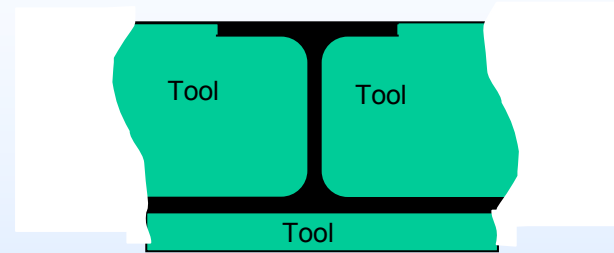
# Use Scenario and Problem Statement

## Composite System Cure Requirements

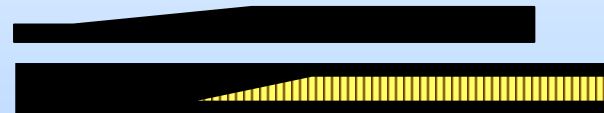


- Resin chemistry requirements
- In-cure and residual stresses
- Minimum and maximum rates
- Minimum and maximum hold times
- Intermediate temperature holds

## Design and Tooling Requirements



Thermally massive tooling, inserts  
Co-cure Tail, Ti Wing Root

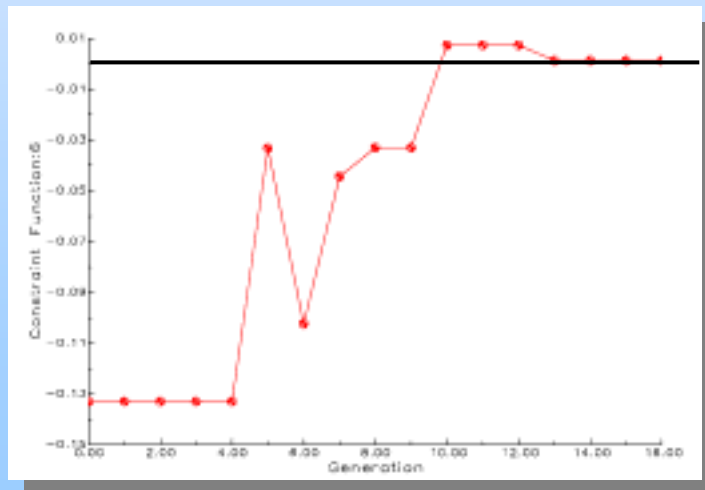
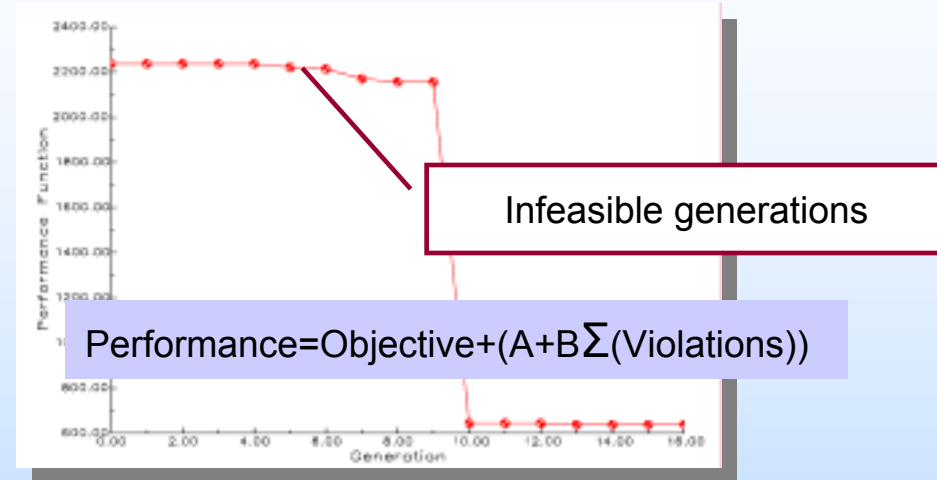
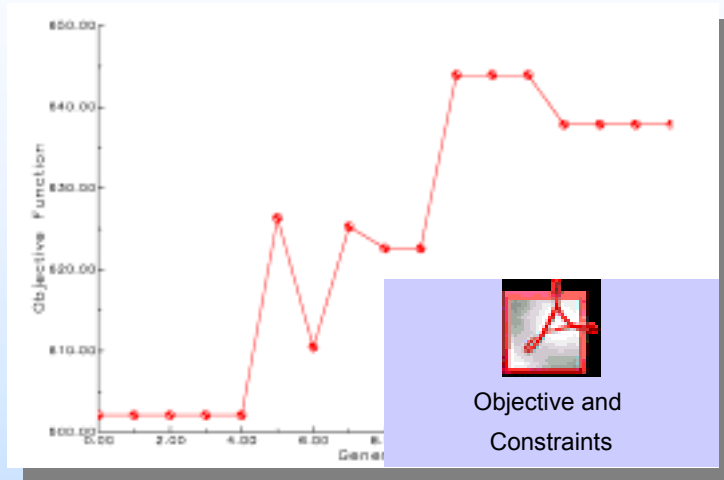


Thick and Thin Sections  
Keel beams, Attachment points  
Combinations of Above

Evaluate Design Driven Requirements Relative to Material and Processing Requirements for Heat-up Rate and Exotherm Producibility Issues



## Representative Results: Thin part, thick aluminum tool



### Important constraints

- 4 - Minimum part heat-up rate at ramp 2
- 5 - Maximum time at final cure temperature
- 6 - Minimum time at final cure temperature
- 7 - Maximum acceptable heat-up gradient

Resource needs: ~ 550 evaluations

3 hrs wall clock time (100 workstations)



# Conclusions

- Demonstrated Integrated Producibility-Processing-RDCS Design Tool
- Tool was used to search for feasible heat-up cure cycles
- Feasible designs were not found in all cases
  - Insight into the process
  - Options: change tooling material or relax constraints
  - This is precisely what the AIM-C facilities are intended for:

Identify and solve design/producibility problems early to avoid cost and schedule overruns



# AIM-C Reduces Time and Cost of Insertion by Understanding the Actual Manufacturing and Structural Analysis of Real Applications

